WHP Cruise Summary Information

WOCE section designation	I08N/I05E
Expedition designation (EXPOCODE)	316N145_7
Chief Scientist(s) and their affiliation	Lynne Talley, SIO
Dates	1995.03.10 - 1995.04.15
Ship	KNORR
Ports of call	Colombo, Sri Lanka to Fremantle, Australia
Number of stations	165
Geographic boundaries of the stations	6˚30.14''N 79˚35.17''E 114˚52.45''E 0˚15.00''S
Floats and drifters deployed	20 Floats and 9 Drifters
Moorings deployed or recovered	none
Contributing Authors (In order of appearance)	F. Delahoyde M. Beaupre E. Firing P. Hacker J. Hummon M. Thatcher

WHP Cruise and Data Information

Instructions: Click on any highlighted item to locate primary reference(s) or use navigation tools above.

Cruise Summary Information	**Hydrographic Measurements**
Description of scientific program	CTD - general
	CTD - pressure
Geographic boundaries of the survey	CTD - temperature
Cruise track (figure)	CTD - conductivity/salinity
Description of stations	CTD - dissolved oxygen
Description of parameters sampled	
Bottle depth distributions (figure)	Salinity
Floats and drifters deployed	Oxygen
Moorings deployed or recovered	Nutrients
	CFCs
Principal Investigators for all measurements	Helium
Cruise Participants	Tritium
	Radiocarbon
Problems and goals not achieved	CO2 system parameters
Other incidents of note	Other parameters
Underway Data Information	**Acknowledgments**
Navigation	**References**
Bathymetry	
Acoustic Doppler Current Profiler (ADCP)	**DQE Reports**
Thermosalinograph and related measurements	
XBT and/or XCTD	CTD
Meteorological observations	S/O2/nutrients
Atmospheric chemistry data	CFCs
	14C
	Data Status Notes

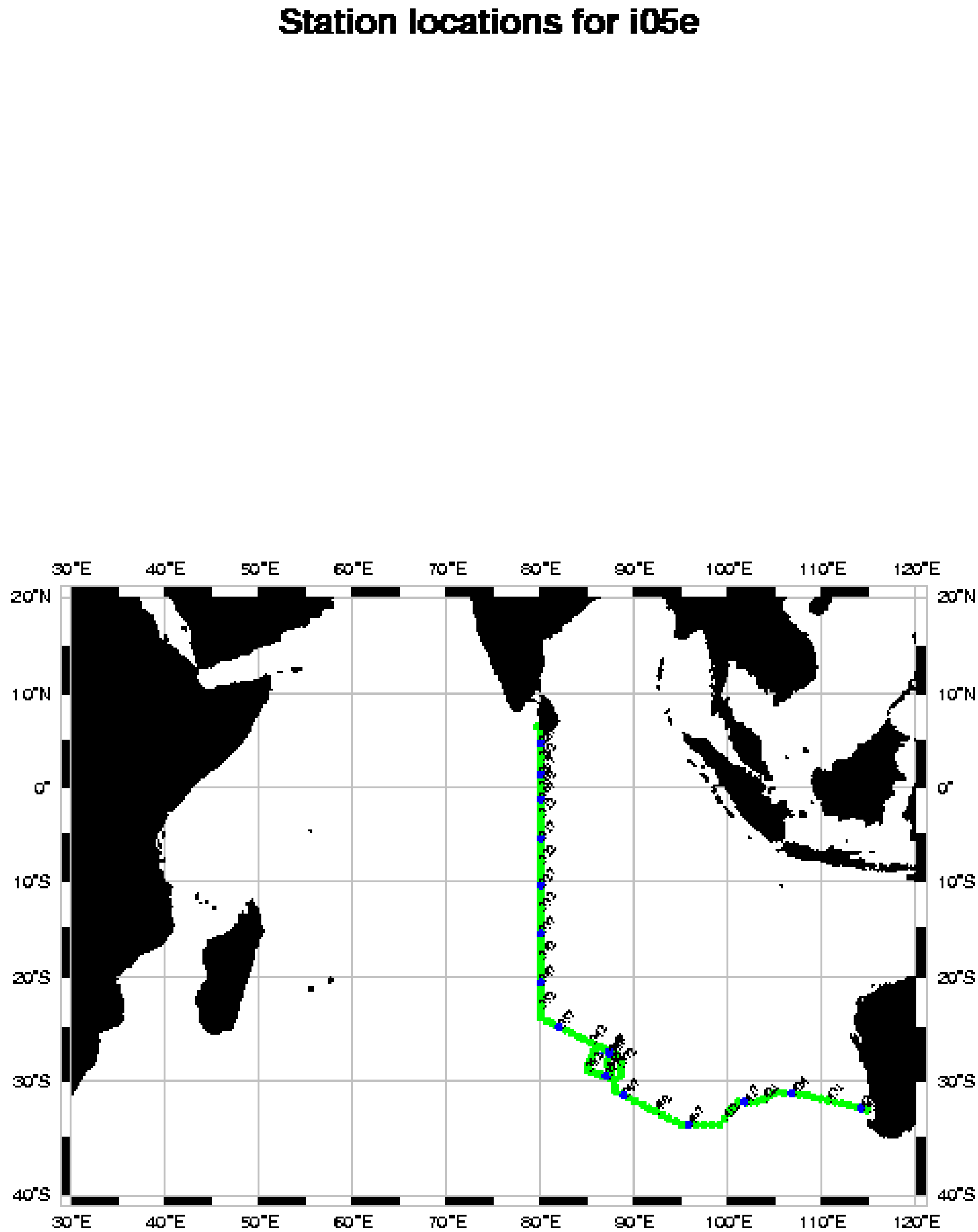

Fig. 1 (Produced from.SUM files by WHPO)

Cruise Report - WOCE I08N/I05E

A. Cruise narrative

1. Highlights

a. Expedition: WOCE I08N/I05E (R/V Knorr 145-7)

b. Expocode: 316N145/7

c. Chief Scientist:
Lynne D. Talley
Scripps Institution of Oceanography 0230
La Jolla, CA 92093-0230 USA
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d. Ship: R/V Knorr, Captain C. Swanson

e. Ports of Call: Colombo, Sri Lanka
Fremantle, Australia

f. Cruise dates: 10 March 1995 - 15 April 1995

2. Cruise summary

a. Cruise track in Fig.1

b. Sampling (Fig. A.2)

165 CTD/36-bottle rosette stations; 155 stations included LADCP

Water sampling through the water column for salinity, oxygen, nitrate, phosphate, silicate, nitrite, CFC's, total CO2, alkalinity, C14, helium, tritium, barium. Surface sampling at selected station locations for delta-C13, phytoplankton growth rates and calcite.

Underway sampling programs are listed in section A.5.

Listings of parameters measured at each station are given in the .SUM file.

c. Floats and drifters deployed (Fig. A.3)

20 ALACE floats
9 surface drifters

Identification numbers, locations and times are given in the .SUM file.

d. No mooring deployments

3. Principal Investigators

William Balch	Surface calcite	U. Miami	balch@rcf.rsmas.miami.edu
Mark Bushnell	Surface drifters	NOAA-AOML	bushnell@saturn.aoml.erl.gov
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William Smethie	Chlorofluorocarbons	LDEO	bsmeth@ldeo.columbia.edu
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Lynne Talley	CTD-hydrography	SIO	ltalley@ucsd.edu
Ray Weiss	Underway pCO2, pN2O, CH4	SIO	rfweiss@ucsd.edu
Christopher Winn	Carbon dioxide	U. Hawaii	cwinn@mpl.ucsd.edu

Abbreviations and addresses for tables above and below:

LDEO: Lamont-Doherty Earth Observatory, Palisades, NY 10964
NARA: National Aquatic Resources Agency, Crow Island, Mattakkuliya, Colombo 15, Sri Lanka
NOAA/AOML: National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Marine Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149
NOAA/PMEL: National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory. Hatfield Marine Science Center, 2115 SE OSU Dr., Newport, OR 97365
OSU: College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503
Princeton: Princeton University, Geology Dept., Guyot Hall, Princeton, NJ 08544
SIO: Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093 USA
SIO/ODF: SIO Oceanographic Data Facility, UCSD, La Jolla, CA 92093-0214 USA

TAMU: Texas A&M University, College Station, TX 77843
U.C. Santa Cruz: Rau address is NASA-Ames, MS239-4 Moffett Field, CA 94035-1000
U.Hawaii: University of Hawaii, 1000 Pope Rd., Honolulu, HI 96822
U. Miami: University of Miami/RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33143
WHOI:Woods Hole Oceanographic Institution, Woods Hole, MA 02543

4. Scientific Programme and Methods

a. Narrative

R/V Knorr departed Colombo, Sri Lanka for its seventh leg of cruise 145 on March 10, 1995. This was the third WOCE hydrographic leg on the Knorr in the Indian Ocean. I08N/I05E was supported by the National Science Foundation's Ocean Sciences Division. I08N/I05E was the second WOCE hydrographic leg on the Knorr with basic technical support from Scripps Institution of Oceanography's Oceanographic Data Facility. There were almost no problems with the basic sampling program. The weather was excellent for the most part.

Stations were numbered consecutively from the beginning of the R/V Knorr 145-5 work on I08S/I09N (McCartney, chief scientist). The first station on I08N/I05E was numbered 278 and was a test station. The first complete station was 279. The last station was 442.

The cruise plan called for sampling southward from Sri Lanka along 88 E to 24 S, and then angling southeastward to the junction of the Ninety-East Ridge and Broken Ridge. Then the track was to proceed eastwards nominally following the 1987 section along about 32 S. The goals of the sampling were to obtain a section through the center of the Central Indian Basin, and to repeat the crossing of the northward flow of deep water just to the west of Australia. Particular attention was to be paid to a potential source of deep water for the Central Indian Basin, through a possible sill in the Ninety-East Ridge, located at about 28 S. The cruise was not long enough to allow sampling of another source of slightly less dense water near about 34 S. However, there were enough extra days in the schedule, due to the excellent weather and good condition of the sampling equipment, to allow extra sampling around the 28 S sill. It was also possible to deviate from the 32 S section, and sample in the deep water south of Broken Ridge instead of along the top of the ridge. Between Broken Ridge and Australia we chose to move the section slightly north of the original position of I05E in order to better resolve whether the deep flow splits around Dirck Hartog Ridge.

All stations were to within 10 meters of the bottom and included a rosette/CTD cast. Basic station spacing was 30 nm, closing to 20 nm for 3 S - 1 S and 1 N - 3 N, and to 15 nm for 1 S to 1 N. Station spacing at the Sri Lankan and Australian coasts and various crossings of the NinetyEast Ridge and Broken Ridge was less than 30 nm and dictated by topography.

Sampling was done with a 36-place General Oceanics pylon on a rosette frame with 10-liter bottles and a CTD (SIO/ODF CTD 1), transmissometer, altimeter and pinger. The

CTD data stream consisted of elapsed time, pressure, two temperature channels, conductivity, oxygen, altimeter and transmissometer signals. All profiles were full water column depth. Water samples were collected for analyses of salt, oxygen, silica, phosphate, nitrate and nitrite on all stations and of CFC-11, CFC-12, carbon tetrachloride, helium-3, helium-4, tritium, AMS C14, pCO2, total dissolved inorganic carbon, alkalinity, and barium on selected stations. Water sample depths for the basic physical oceanography program are shown in Fig. A.2.

Station times for the CTD/rosette are shown in Fig. A.4. Wire speeds were generally 60 meters/minute for downcasts and 70 meters/minute for upcasts; because of stops for bottle trips and slower speeds in the upper 200 meters, the average wire speed for all stations was 55-58 meters/minute.

On all but 10 stations, one of Eric Firing's RDI lowered acoustic doppler profilers (LADCP) was mounted inside the rosette frame. Two different LADCP's were used, a narrow band operating at 300kHz and a broad band operating at 150kHz. The former was intended to be the principal instrument, but suffered a failure at station 291. The broad band LADCP was mounted at station 294 and used thereafter.

At 100 stations surface water was filtered for particulate organic carbon (Rau) for later isotopic analysis with the resulting 13C/12C to be correlated with surface CO2. On 65 stations, 200 liters of surface water were filtered for additional analysis of lipid components.

Particulate organic materials were filtered from the ship uncontaminated seawater supply at twelve stations near the equator. Stable carbon isotopic compositions of phytoplankton will be determined by analyses of individual lipid biomarker compounds in B. Popp's laboratories at the University of Hawaii. The goal of this work is to distinguish the extent to which phytoplankton growth rates influence correlations between the concentration of surface water CO2 and isotopic fractionation exhibited by phytoplankton. Approximately 1600-1800 litres of seawater were filtered at each station. Additionally, duplicate 20-mL samples of seawater were collected from the same seawater supply to determine the carbon isotopic composition of total dissolved inorganic carbon.

Underway shipboard ADCP data were logged (Firing). There were problems with the device resulting in no data return between Sri Lanka and 3 N.

Underway measurements included pCO2 (Key and Weiss), pN2O (Weiss), methane (Weiss) and the various variables of the Knorr's IMET system (surface water temperature and conductivity, oxygen, meteorological parameters, GPS navigation, ship's speed and heading). Bathymetry was recorded every 5 minutes from the Knorr's PDR for our own use in constructing vertical sections and as additional input to the overall database (Smith - Geological Data Center at Scripps Institution of Oceanography). We found large problems with the existing Gebco maps in the vicinity of the 28 S sill in the Ninety-East Ridge; this region had not been well surveyed in the past. Preliminary results will be reported in WOCE notes.

b. Bottle locations – (Fig. A.2)

c. Vertical sections

Potential temperature, salinity, oxygen, silicate, nitrate, phosphate, potential density are distributed as an appendix to the report.

d. Interlaboratory comparisons

No interlaboratory comparisons were made per se on I08N/I05E, but water sample results were compared with preliminary data acquired on I09N (Gordon, chief scientist, R/V Knorr), I08S (McCartney, chief scientist, R/V Knorr), the 1987 occupation of I05 (Toole and Warren), the 1979 cruise at 12 S on the Wilkes, the 1976 cruise at 18 S on the Atlantis II, and the 1978 Geosecs stations along 80 E. Comparisons of I08N/I05E salinity, oxygen, silica, nitrate and phosphate with data from the I08S, 1987 I05, and 12 S cruises and one of the Geosecs stations are shown in Figs. A.5-8.

WHP required accuracies for deep water values

salinity	.002 if corrected for SSW batch
oxygen	1% = .03-.04 ml/l
nitrate	1% = .3-.4 umol/l
phosphate	1% = .02-.03 umol/l
silicate	1% = 1-1.5 umol/l

d.1. I08N/I05E compared with I09N (3 N, 80 E) (no figure)

I09N stations (3/95):	276-277	ODF S,O2,nuts/ SSW P126
I08N/I05E stations (3/95):	291-294	ODF S,O2,nuts/ SSW P126

Differences in all properties were within the range of actual variability of the deep waters. These stations occurred within several weeks of each other, and were done by the same technical group although the individual personnel differed.

d.2. I08N/I05E compared with Geosecs stations along 80 E (Fig. A.5)

Geosecs stations (4/78):	447-452 ODF S,O2,nuts
I08N/I05E stations (3/95):	groups of three surrounding the Geosecs stations. ODF S,O2,nuts

The Geosecs stations were spaced 5 latitude apart, so comparisons could only be made with individual stations. The method for measuring phosphate concentration was significantly changed following the Geosecs measurements, and the change accounts for the large offset between the two data sets.

Salinity: there appears to be an offset of about 0.003, with the Geosecs salinity higher.
Oxygen: no offset between the data sets.

Silicate: no offset between the data sets.
Nitrate: no offset between the data sets.
Phosphate: Geosecs is 0.04 - 0.06 umol/l lower.

d.3. I08N/I05E compared with R/V Wilkes stations along 12 S (Fig. A.6)

Wilkes stations (4/79): 17-21
I08N/I05E stations (3/95): 328-332

Both the nitrate and phosphate are more scattered in the 1979 data set, while salinity, oxygen and silicate agree fairly well. The scatter might be due to true variations in properties.

Salinity: no offset
Oxygen: no offset
Silicate: no offset, similar scatter
Nitrate: no offset. Scatter of 12 S data is about 0.7 umol/l compared with 0.4 umol/l for I08N/I05E.
Phosphate: no offset. Scatter of 12 S data is about 0.05 umol/l compared with .02 umol/l for I08N/I05E.

d.4. I08N/I05E compared with R/V Atlantis II stations along 18 S (no figure)

Atlantis II stations (8/76): 2298-2302
I08N/I05E stations (3/95): 342-344

The AII dataset has a large number of fliers, and the overall precision for the bottle data is lower than on I08N/I05E.
Salinity: no offset. Scatter of I08N/I05E data is 0.002. Scatter of AII data is greater than 0.005. A number of individual values are more than 0.02 high.
Oxygen: no offset. Scatter of I08N/I05E data is 0.07 ml/l. Scatter of AII data is about 0.2 ml/l.
Silicate: no offset. Scatter of I08N/I05E is 2 umol/l. Scatter of AII data is almost 10 umol/l.
Nitrate: no AII data.
Phosphate: AII phosphates are 0.08 umol/l hower than I08N/I05E. This offset is similar to the Geosecs offset and is probably due to the same analytical changes.

d.5. I08N/I05E compared with R/V Charles Darwin stations along 32 S (Fig. A.7)

Darwin stations (5/87): 67-69
I08N/I05E stations (4/95): 377-381

This is a region of large lateral variability. The two data sets are essentially equivalent in every parameter. Even the CTD traces overlay remarkably well, within the precision expected for a single cruise.

d.6.   I08N/I05E compared with I08S (Fig. A.8)

I08S stations (12/94):   10-12
I08N/I05E stations (4/95): 405-407

All properties overlay very well. Since the work was carried out by the two different technical groups who will be supporting all of the Indian Ocean WHP, this bodes very well for the overall data set.

Summary

Salinity and oxygen accuracy and precision are within WOCE requirements on I08S. Nutrient accuracy and precision are within WOCE requirements. There is no offset between the I08N/I05E values and the I09N values (both collected by SIO/ODF). There is no offset between the I08N/I05E values and the I08S values (the latter salinity and oxygen collected by WHOI and nutrients by Oregon State University).

5. Underway measurements

a. Navigation - GPS. Bathymetry - PDR.

b. ADCP - RDI vessel mounted 150kHz ADCP. See comments above.

c. Thermosalinograph and meteorological measurements - using the IMET system.

d. No XBT's or XCTD's.

e. Meteorological observations: weather data logged at each station. Continuous measurements from the IMET system.

f. pCO2, pN2O and methane: in water and air

6. Major problems and goals not achieved

There were no problems resulting in major shortfalls in numbers, spacing, or coverage of the stations. There were no major problems with any of the basic WOCE analyses. The shipboard ADCP was not functioning between Sri Lanka and 3 N.

7. Other incidents of note - none

8. Cruise Participants:

For addresses, see list following principal investigator table above

Molly Baringer	co-chief scientist	NOAA/AOML	baringer@aoml.erl.gov
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Jim Costello	nutrients	SIO/ODF	
Joshua Curtice	helium and tritium	WHOI	jmc@kopernik.whoi.edu
Frank Delahoyde	CTD processing	SIO/ODF	fdelahoyde@ucsd.edu
Tilak Dharmaratne	observer	NARA/Sri Lanka	
Rebecca Esmay	CFCs	LDEO	esmay@lamont.ldgo.columbia .edu
Eugene Gorman	CFCs	LDEO	
Ron Greene	helium	NOAA/PMEL	greene%new@pmel.noaa.gov
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Leonard Lopez	oxygens, deck	SIO/ODF	leo@odf.ucsd.edu
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Kamal Tennakoon	observer	NARA/Sri Lanka	
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B. Description of Measurement techniques and calibrations

B.1. Preliminary report on CTD calibrations

(Frank Delahoyde, May 23, 1995)

CTD data were collected with a modified NBIS Mark III CTD (ODF CTD #1). This instrument provided pressure, temperature, conductivity and dissolved O2 channels, and additionally measured a second temperature (FSI temperature sensor) as a calibration check. Other data channels included elapsed-time, an altimeter, several power supply voltages and a transmissometer. The instrument supplied a standard 15-byte NBIS-format data stream at a data rate of 25 fps. Modifications to the instrument included revised pressure and dissolved O2 sensor mountings; ODF-designed sensor interfaces for O2, FSI PRT and the SeaTech transmissometer; implementation of 8-bit and 16-bit multiplexer channels; an elapsed-time channel; instrument id in the polarity byte and power supply voltages channels.

The CTD pressure sensor mounting had been modified to reduce the dynamic thermal effects on pressure. The sensor was attached to a 20 cm length of coiled stainless-steel tubing threaded into the end-cap pressure port. The transducer was also wrapped in foam rubber. The NBIS temperature compensation circuit on the pressure interface was disabled; all thermal response characteristics were modeled and corrected in software.

The O2 sensor was deployed in a pressure-compensated holder assembly mounted separately on the rosette frame and connected to the CTD by an underwater cable. The O2 sensor interface was designed and built by ODF using an off-the-shelf 12-bit A/D converter. The transmissometer interface was a similar design.

Although the secondary temperature sensor was located within 1 meter of the CTD conductivity sensor, it was not sufficiently close to calculate coherent salinities. It was used as a secondary temperature calibration reference rather than as a redundant sensor, eliminating the necessity of deploying mercury or electronic DSRTs for calibration checks.

Standard CTD maintenance procedures included soaking the conductivity and O2 sensors in distilled water between casts to maintain sensor stability, and protecting the CTD from exposure to direct sunlight or wind to maintain an equilibrated internal temperature.

The General Oceanics 1016 36-place pylon provided generally reliable operation and positive confirmation of all bottle trip attempts. The General Oceanics pylon deck unit was not used. Instead, an ODF-built deck unit and external power supply were employed. The pylon emits a confirmation message containing its current notion of bottle trip position, an invaluable aid in sorting out mis-trips.

B.1.1. Laboratory Calibration Procedures

Laboratory calibrations of the CTD pressure and temperature sensors were used to generate tables of corrections applied by the CTD data acquisition and processing software at sea.

Pressure and temperature calibrations were last performed on CTD #1 at the ODF Calibration Facility (La Jolla) in December 1994, immediately prior to WOCE I09N.

The CTD pressure transducer was calibrated in a temperature- controlled water bath to a Ruska Model 2400 Piston Gauge pressure reference. Calibration curves were measured at 0.07 and 31.91 C to two maximum loading pressures (1400 and 6080 db). Figure B.1.1 summarizes the laboratory pressure calibration performed in December 1994.

Additionally, dynamic thermal-step response tests were conducted from 26.7 C to 3.4 C and from 3.6 C to 25.7 C. CTD PRT temperatures were calibrated to an NBIS ATB-1250 resistance bridge and Rosemount standard PRT. The primary CTD temperature was offset by 2.0 C to avoid the 0-point discontinuity inherent in the internal digitizing circuitry.

Figure B.1.2 summarizes the laboratory temperature calibration performed on the primary PRT December 1994.

These calibration procedures will be repeated when the instrument is returned to ODF.

B.1.2. Shipboard Calibration Procedures

I08N5E is the second of possibly 6 consecutive Indian Ocean legs for this CTD. Transfer standards and redundant sensors are being used as calibration checks, with the intent of shipping the instrument back for full recalibration only if significant changes are noted in pressure or temperature.

A Paroscientific DigiQuartz secondary pressure reference was used as a pressure calibration transfer standard. An FSI PRT sensor was deployed as a second temperature channel and compared with the primary PRT channel on each cast.

CTD conductivity and dissolved O2 were calibrated to flin-situfR check samples collected during each rosette cast.

B.1.2.1. Pressure and Temperature

The final pressure and temperature calibrations will be determined when CTD #1 is returned to ODF. Based on the conductivity calibration, there were no significant shifts in the CTD pressure or temperature, although comparisons between the primary and secondary PRT channels during the previous leg (I09N) showed a drift of +0.008 C. This drift is attributed to the secondary temperature channel, as the conductivity calibration did not show any shifts that could correspond to temperature changes of this magnitude. This same FSI PRT was used throughout I08N5E and showed an essentially constant offset from the primary PRT of +0.009 C. Figure B.1.3 summarizes the comparison between the primary and secondary PRT channels. The response times of the sensors were first matched, then the temperatures compared for a series of standard depths from each CTD down-cast.

B.1.2.2. Conductivity

The CTD rosette trip pressure and temperature were used with the bottle salinity to calculate a bottle conductivity. Differences between the bottle and CTD conductivities were then used to derive a conductivity correction as a linear function of conductivity.

Conductivity differences were first fit to CTD conductivity for groupings of 5 consecutive casts, to determine conductivity slope changes and detect abrupt calibration shifts not already noted. No slope changes or abrupt shifts were found. The slopes are summarized in Figure B.1.4.

The mean conductivity slope (-0.001087 mmhos/cm) was used for all casts, as no significant linear trend or shifts were found. CTD conductivity offsets were determined for each cast from the deepest bottle conductivities. Figure

(SN2 summarizes the applied conductivity offsets by station number.

Figures B.1.6 and B.1.7 summarize the residual differences between bottle and CTD salinities after applying the conductivity correction.

3 sigma from the mean residual in Figures B.1.7 and B.1.8, or (+- 0.0023 PSU for all salinities and (+-0.001 PSU for deep salinities of repeatability of the bottle salinities (Autosal, operators and samplers). This limit agrees with station overlays of deep TS. Within a cast (a single salinometer run), the precision of bottle salinities appears to exceed 0.001 PSU. The precision of the CTD salinities appears to exceed 0.0005 PSU.

B.1.2.3. CTD Dissolved Oxygen

There are a number of problems with the response characteristics of the Sensormedics O2 sensor used in the NBIS Mark III CTD, the major ones being a secondary thermal response and a sensitivity to profiling velocity. Because of these problems, CTD rosette trip data cannot be directly calibrated to O2 check samples. Instead, down-cast CTD O2 data are derived from the up-cast rosette trips along isopycnal surfaces. The differences between CTD O2 modeled from these derived values and check samples are then minimized using a non-linear least-squares fitting procedure. Figures B.1.9 and B.1.10 show the residual differences between the corrected CTD O2 and the bottle O2 (ml/l) for each station.

Note that the mean of the differences is not zero, because the O2 values are weighted by pressure before fitting. The standard deviations of 0.05 ml/l for all oxygens and 0.03 ml/l for deep oxygens are only intended as metrics of the goodness of the fits. ODF makes no claims regarding the precision or accuracy of CTD dissolved O2 data.

The general form of the ODF O2 conversion equation follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. ODF does not use a digitized O2 sensor temperature to model the secondary thermal response but instead models membrane and sensor temperatures by low-pass filtering the PRT temperature. In-situ pressure and temperature are filtered to match the sensor response. Time-constants for the pressure response tau sub p, and two temperature responses tau sub Ts and tau sub Tf are fitting parameters. The sensor current, or Oc, gradient is approximated by low-pass filtering 1 Oc differences. This term attempts to correct for reduction of species other than O2 at the cathode. The time-constant for this filter, tau sub og, is a fitting parameter. Oxygen partial-pressure is then calculated: (equation deleted for this ascii version)

where:
Opp = Dissolved O2 partial-pressure in atmospheres (atm);
Oc = Sensor current (muamps);
fsat (S,T,P) = O2 saturation partial-pressure at S,T,P (atm);
S = Salinity at O2 response-time (PSUs);
T = Temperature at O2 response-time (C);
P = Pressure at O2 response-time cibars);
Pl = Low-pass filtered pressure cibars);
Tf = Fast low-pass filtered temperature (C);
Ts = Slow low-pass filtered temperature (C);
dOc/dt = Sensor current gradient (muamps/secs).

B.1.3. CTD Data Acquisition, Processing and Control System

The CTD data acquisition, processing and control system consisted of a Sun SPARCstation LX computer workstation, ODF-built CTD and pylon deck units, CTD and pylon power supplies and a VCR recorder for real-time analog backup recording of the seacable signal. The Sun system consisted of a color display with trackball and keyboard (the CTD console), 18 RS-232 ports, 2.5 GB disk and 8-mm cartridge tape. Two other Sun LX systems were networked to the data acquisition system, as well as to the rest of the networked computers aboard the Knorr. These systems were available for real-time CTD data display as well as providing hydrographic data management and backup. Two HP 1200C color inkjet printers provided hardcopy from any of the workstations.

The CTD FSK signal was demodulated and converted to a 9600 baud RS-232C binary data stream by the CTD deck unit. This data stream was fed to the Sun SPARCstation. The pylon deck unit was also connected to the Sun through a bi-directional 300 baud serial line, allowing rosette trips to be initiated and confirmed through the data acquisition software. A bitmapped color display provided interactive graphical display and control of the CTD rosette sampling system, including real-time raw and processed data displays, navigation, winch and rosette trip displays.

The CTD data acquisition, processing and control system was prepared by the console watch a few minutes before a deployment. A console operations log was maintained for each deployment, containing a record of every attempt to trip a bottle as well as any pertinent comments. Most CTD console control functions, including starting the data acquisition, were performed by pointing and clicking a trackball cursor on the display at pictures representing functions to perform. The system would then present the operator with a short dialog prompting with automatically- generated choices that could either be accepted as default or overridden. The operator was instructed to turn-on the CTD and pylon power supplies, then to examine a real-time CTD data display on the screen for stable voltages from the underwater unit. Once this was accomplished, the data acquisition and processing was begun and a time and position automatically associated with the beginning of the cast. A backup analog recording of the CTD signal was made on a VCR tape, which was started. A rosette trip display and pylon control window then popped up, giving visual confirmation that the pylon was initializing properly. Various plots and displays were initiated. When all was ready, the console operator informed the deck watch by radio.

Once the deck watch had deployed the rosette and informed the console operator that the rosette was at the surface (a formality, since the data acquisition system had already made it known), the console operator provided the winch operator with a target depth (wire-out) and lowering rate (normally 60 meters/minute for this package). The package would then begin its descent.

The console operator would examine the processed CTD data during descent via interactive plot windows on the display, which could also be initiated from other workstations on the network. Additionally, the operator would decide where to trip bottles on the up-cast, noting this on the console log. The PDR was monitored to insure the bottom depth was known at all times.

The watch leader would assist the console operator when the package was 400 meters above the bottom, and verify the range to the bottom using the distance between the bottom reflection and pinger signal displayed on the PDR. At 200 meters above the bottom the altimeter would normally begin signaling a bottom return on the console. The on-screen winch displays allowed the console operator to refine the target depth relayed to the winch operator and safely approach to within 10 meters of the bottom.

Bottles would be tripped by pointing the console trackball cursor at a graphic firing control and clicking a button. The data acquisition system would respond with the CTD rosette trip data and a pylon confirmation message in a window. All tripping attempts were noted on the console log. The console operator would then direct the winch operator to the next bottle stop. The console operator was also responsible for generating the sample log for the cast.

After the last bottle was tripped, the console operator would direct the deck watch to bring the rosette on deck. Once on deck, the console operator would terminate the data acquisition and turn-off the CTD, pylon and VCR recording. The VCR tape was filed. Frequently the console operator would also bring the sample log to the rosette room and serve as the fIsample copfR.

B.1.4. CTD Data Processing

ODF CTD processing software consists of some 35-odd programs running under the Unix operating system. The initial CTD processing program (ctdba) is used either in real-time or with existing raw data sets to:

- Convert raw CTD scans into scaled engineering units, and assign the data to logical channels;
- Filter specific channels according to specified filtering criteria;
- Apply sensor or instrument-specific response-correction models;

- Provide periodic averages of the channels corresponding to the output time-series interval; and
- Store the output time-series in a CTD-independent format.

Once the CTD data are reduced to a standard-format time-series, they can be manipulated in a number of various ways. Channels can be additionally filtered. The time-series can be split up into shorter time-series or pasted together to form longer time-series. A time-series can be transformed into a pressure-series, or a different interval time-series. Calibration corrections to the series are maintained in separate files and are applied whenever the data are accessed.

ODF data acquisition software acquired and processed the CTD data in real-time, providing calibrated, processed data for interactive plotting and reporting during a cast. The 25 hz data from the CTD were filtered, response-corrected and averaged to a 2 hz time- series. Sensor correction and calibration models were applied to pressure, temperature, conductivity and O2. Rosette trip data were extracted from this time-series in response to trip initiation and confirmation signals. The calibrated 2 hz time-series data were stored on disk (as was the 25 hz raw data) and were available in real-time for reporting and graphical display. At the end of the cast, various consistency and calibration checks were performed, and a 2.0 db pressure-series of the down-cast was generated and subsequently used for reports and plots.

CTD plots generated automatically at the completion of deployment were checked daily for potential problems. The two PRT temperature sensors were inter-calibrated and checked for sensor drift. The CTD conductivity sensor was monitored by comparing CTD values to check-sample conductivities and by deep TS comparisons with adjacent stations. The CTD dissolved O2 sensor was calibrated to check-sample data.

A few casts exhibited conductivity offsets due to biological or particulate artifacts. Some casts were subject to O2 channel noise, which was traced to moisture in the interconnect cable to the sensor. In these cases the 2 hz time-series were additionally filtered after the cast. Table B.1 provides a list of all CTD casts requiring special attention.

Cast	Problems	Solutions
282/01	o2 very noisy, died	o2 unusable.
283/01	o2 sensor replaced, o2 very noisy	o2 unusable.
289/01	cond offset on u/c	cond calibration shift.
296/01	bottom cond spike	Filtered.
318/01	cond offset	Filtered.
319/01	cond offset on u/c	cond calibration shift.
326/01	o2 noise	Filtered.
327/01	o2 noise	Filtered.
329/01	cond offset on d/c (returns)@1.0	Filtered.
theta (-.001)		
331/01	cond offset on d/c	cond calibration shift.

331/01	o2 noise	Filtered.
332/01	o2 noise	Filtered.
336/01	o2 noise	Filtered.
360/01	Reterminated seacable.	No effect on CTD data.
377/01	cond spike on d/c @3.1 theta	Filtered.
394/01	cond noise at bottom	Filtered.
401/01	+0.002 cond offset @ bottom	Filtered.
405/01	cond spike @ d/c bottom	Filtered.
412/01	cond spike @1000M d/c	Filtered.
420/01	Pylon conductor failed	Cast aborted during u/c.
423/01	-0.001 cond spike@ u/c bottom	Filtered.
426/01	-0.002 cond spike on d/c	Filtered.
436/01	cond offset at bottom	cond calibration shift.
437/01	cond offset at bottom	cond calibration shift.

Table B.1. Tabulation of problem CTD casts.

B.1.5. CTD References

Brown, N.L. and Morrison, G.K., WHOI/Brown conductivity, temperature and depth microprofiler, Woods Hole Oceanographic Institution Technical Report No. 78-23.

Millard, R.C. Jr., CTD calibration and data processing techniques at WHOI using the practical salinity scale, Proc. Int. STD Conference and Workshop, La Jolla, Mar. Tech. Soc., 19pp. (1982).

Owens, W.B. and Millard, R.C. Jr., A new algorithm for CTD oxygen calibration", Journ. of Am. Meteorological Soc., 15, 621 (1985).

B.2. Preliminary report on bottle sampling

(Frank Delahoyde, May 23, 1995)

At the end of each rosette deployment water samples were drawn from the bottles in the following order: CFCs; Helium-3; Oxygen; Total CO2; Alkalinity; AMS C14 and C13; Tritium; Nutrients; Salinity; Barium.

The correspondence between individual sample containers and the rosette bottle from which the sample was drawn was recorded on the sample log for the cast. This log also included any comments or anomalous conditions noted about the rosette and bottles. One member of the sampling team was designated the fIsample copfR, whose sole responsibility was to maintain this log and insure that sampling progressed in proper drawing order.

Normal sampling practice included opening the drain valve before opening the air vent on the bottle, indicating an air leak if water escaped. This observation together with other diagnostic comments (e.g., "lanyard caught in lid", "valve left open") that might later prove useful in determining sample integrity were routinely noted on the sample log.

Drawing oxygen samples also involved taking the sample draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful in determining leaking or mis- tripped bottles.

Once individual samples had been drawn and properly prepared, they were distributed to their laboratory for analysis. Oxygen, nutrients and salinity analyses were performed on computer-assisted (PC) analytical equipment networked to Sun SPARCStations for centralized data analysis. The analyst for a specific property was responsible for insuring that their results updated the cruise database.

B.2.1. Bottle Data Processing

The first stage of bottle data processing consisted of verifying and validating individual samples, and checking the sample log (the sample inventory) for consistency. At this stage, bottle tripping problems were usually resolved, sometimes resulting in changes to the pressure, temperature and other CTD properties associated with the bottle. Note that the rosette bottle number was the primary identification for all samples taken from the bottle, as well as for the CTD data associated with the bottle. As all CTD trips were retained (whether confirmed or not), resolving bottle tripping problems simply consisted of assigning the right rosette bottle number to the right CTD rosette trip.

Diagnostic comments from the sample log were then translated into preliminary WOCE quality codes, together with appropriate comments. Each code indicating a potential problem would be investigated.

The second stage of processing would begin once all the samples for a cast had been accounted for. All samples for bottles suspected of leaking were checked to see if the property was consistent with the profile for the cast, with adjacent stations and where applicable, with the CTD data. All comments from the analysts were examined and turned into appropriate water sample codes. Oxygen flask numbers were verified, as each flask is individually calibrated and significantly affects the calculated O2 concentration.

The third stage of processing would continue throughout the cruise (and indeed until the data set is considered "final"). Various property-property plots and vertical sections were examined for both consistency within a cast and consistency with adjacent stations. In conjunction with this process the analysts would review (and sometimes revise) their data as additional calibration or diagnostic results became available. Assignment of a WHP water sample code to an anomalous sample value was typically achieved through consensus.

WHP water bottle quality flags were assigned with the following additional interpretations:

3: An air leak large enough to produce an observable effect on a sample is identified by a code of 3 on the bottle and a code of 4 on the oxygen. (Small air leaks may have no observable effect, or may only affect gas samples.)
4: Bottles tripped at other than the intended depth were assigned a code of 4. There may be no problems with the associated water sample data.

WHP water sample quality flags were assigned using the following criteria:

1: The sample for this measurement was drawn from a bottle, but the results of the analysis were not (yet) received.
2: Acceptable measurement.
3: Questionable measurement. The data did not fit the station profile or adjacent station comparisons (or possibly CTD data comparisons). No notes from the analyst indicated a problem. The data could be correct, but are open to interpretation.
4: Bad measurement. Does not fit the station profile, adjacent stations or CTD data. There were analytical notes indicating a problem, but data values were reported. Sampling and analytical errors were also coded as 4.
5: Not reported. There should always be a reason associated with a code of 5, usually that the sample was lost, contaminated or rendered unusable.
9: The sample for this measurement was not drawn.

WHP water sample quality flags were assigned to the CTDSAL (CTD salinity) parameter as follows:

2: Acceptable measurement.
3: Questionable measurement. The data did not fit the bottle data, or there was a CTD conductivity calibration shift during the cast.
4: Bad measurement. The CTD data were determined to be unusable for calculating a salinity.
8: The CTD salinity was derived from the CTD down cast, matched on an isopycnal surface.

WHP water sample quality flags were assigned to the CTDOXY (CTD oxygen) parameter as follows:

2: Acceptable measurement.
4: Bad measurement. The CTD data were determined to be unusable for calculating a dissolve oxygen concentration.
5: Not reported. The CTD data could not be reported.
9: Not sampled. No operational dissolved oxygen sensor was present on this cast.

Note that all CTDOXY values were derived from the down cast data, matched to the upcast along isopycnal surfaces.

Table B.2 shows the number of samples drawn and the number of times each WHP sample quality flag was assigned for each basic hydrographic property:

Rosette Samples Stations 278-442

	Reported		WHP Quality Flag					
	Levels	1	2	3	4	5	8	9
Bottle	5483	0	5404	6	40	0	0	33
CTD O2	5483	0	5447	0	36	0	0	0
CTD Salt	5483	0	5444	37	2	0	0	0
Salinity	5424	0	4785	609	25	3	0	2
Oxygen	5436	2	5400	11	15	4	0	4
Nitrate	5679	0	5657	6	14	1	0	1
Nitrite	5679	0	5670	0	7	1	0	1
Phosphate	5679	0	5657	6	14	1	0	1
Silicate	5679	0	5653	1	12	12	0	1

Table B.2. Frequency of WHP quality flag assignments.

B.3. Preliminary report on discrete salinity measurements
(Frank Delahoyde, May 23, 1995)

Salinity samples were drawn into 200 ml Kimax high alumina borosilicate bottles after 3 rinses, and were sealed with custom- made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. As loose inserts were found, they were replaced to ensure a continued airtight seal. Salinity was determined after a box of samples had equilibrated to laboratory temperature, usually within 8-12 hours of collection. The draw time and equilibration time, as well as per-sample analysis time and temperature were logged.

Two Guildline Autosal Model 8400A salinometers (55-654 and 57-396) located in a temperature-controlled laboratory were used to measure salinities. The salinometers were modified by ODF and contained interfaces for computer-aided measurement. A computer (PC) prompted the analyst for control functions (changing sample, flushing) while it made continuous measurements and logged results. The salinometer cell was flushed until successive readings met software criteria for consistency, then two successive measurements were made and averaged for a final result.

The salinometer was standardized for each cast with IAPSO Standard Seawater (SSW) Batch P-126, using at least one fresh vial per cast. The estimated accuracy of bottle salinities run at sea is usually better than 0.002 psu relative to the particular Standard Seawater batch used. PSS-78 salinity [UNES81] was then calculated for each sample from the measured conductivity ratios, and the results merged with the cruise database.

Salinometer 55-654 was used on stations 278-308, and 313-327. It was replaced by salinometer 57-396 on station 309 because of noise problems initially attributed to the ship's power, and later determined to be bath temperature drift. As a result, several boxes of salinities were found have noise-levels in excess of 0.002 PSU, and were excluded from CTD calibrations.

5424 salinity measurements were made and 300 vials of standard water were used. The temperature stability of the laboratory used to make the measurements was good. There were problems with the stability of the salinometer bath temperature, at least partly due to running the bath at the 24 C set-point when the ambient temperature was below 22 C for part of the cruise. The salinities were used to calibrate the CTD conductivity sensor.

B.3.1. Salinity reference UNESCO, 1981. Background papers and supporting data on the Practical Salinity Scale, 1978 UNESCO Technical Papers in Marine Science, No. 37

B.4. Preliminary report on discrete oxygen measurements

(Frank Delahoyde, May 23, 1995)

Samples were collected for dissolved oxygen analyses soon after the rosette sampler was brought on board and after CFC and helium were drawn. Nominal 125 ml volume-calibrated iodine flasks were rinsed twice with minimal agitation, then filled via a drawing tube, and allowed to overflow for at least 3 flask volumes. The sample temperature was measured with a small platinum resistance thermometer embedded in the drawing tube. Draw temperatures were very useful in detecting possible bad trips even as samples were being drawn. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice; immediately after drawing, and then again after 20 minutes, to assure thorough dispersion of the MnO(OH)2 precipitate. The samples were analyzed within 4-36 hours of collection.

Dissolved oxygen analyses were performed with an SIO-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365 nm wavelength ultra-violet light. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml buret. ODF uses a whole-bottle modified-Winkler titration following the technique of Carpenter [Carp65] with modifications by Culberson fIet. alfR [Culb91], but with higher concentrations of potassium iodate standard (approximately 0.012N) and thiosulfate solution (50 gm/l) [Brew74]. Standard solutions prepared from pre-weighed potassium iodate crystals were run at the beginning of each session of analyses, which typically included from 1 to 3 stations. Several standards were made up during the cruise and compared to assure that the results were reproducible, and to preclude the possibility of a weighing error. Reagent/distilled water blanks were determined to account for oxidizing or reducing materials in the reagents. The auto-titrator generally performed very well.

The samples were titrated and the data logged by the PC control software. The data were then used to update the cruise database on the Sun SPARC stations.

Blanks, and thiosulfate normalities corrected to 20 C, calculated from each standardization, were plotted versus time, and were reviewed for possible problems. New thiosulfate normalities were recalculated after the blanks had been smoothed. These normalities were then smoothed, and the oxygen data was recalculated.

Oxygens were converted from milliliters per liter to micromoles per kilogram using the fIin-situfR temperature. Ideally, for whole- bottle titrations, the conversion temperature should be the temperature of the water issuing from the bottle spigot. The sample temperatures were measured at the time the samples were drawn from the bottle, but were not used in the conversion from milliliters per liter to micromoles per kilogram because the software was not available. Aberrant drawing temperatures provided an additional flag indicating that a bottle may not have tripped properly. Measured sample temperatures from mid-deep water samples were about 4-7 C warmer than fIin-situfR temperature. Had the conversion with the measured sample temperature been made, converted oxygen values, would be about 0.08% higher for a 6 C warming (or about 0.2 (mM/Kg for a 250 (mM/Kg sample).

Oxygen flasks were calibrated gravimetrically with degassed deionized water (DIW) to determine flask volumes at ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect bottle volume is detected. All volumetric glassware used in preparing standards is calibrated as well as the 10ml Dosimat buret used to dispense standard Iodate solution.

Iodate standards are pre-weighed in ODF's chemistry laboratory to a nominal weight of 0.44xx grams and exact normality calculated at sea. Potassium Iodate (KIO 3) is obtained from Johnson Matthey Chemical Co. and is reported by the suppliers to be > 99.4% pure. All other reagents are "reagent grade" and are tested for levels of oxidizing and reducing impurities prior to use.

5436 oxygen measurements were made. A problem with UV lamp output appeared to be temperature-related and was solved by providing increased air circulation to the lamp assembly. No other major problems were encountered with the analyses. The temperature stability of the laboratory used for the analyses was fair, at one point late in the cruise failing entirely. Portable fans were then used to restore temperature stability. The oxygen data were used to calibrate the CTD dissolved O2 sensor.

B.4.1. Oxygen References Carpenter, J. H., 1965. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method. Limnology and Oceanography, 1, 141-143. Culberson, C. H. and Williams, R. T., fIet al.fR, Aug 1991. A comparison of methods for the determination of dissolved oxygen in seawater. WOCE Hydrographic Programme Office, Report WHPO 91-2.

B.5. Preliminary report on nutrient measurements

(Marie Beaupre, May 23, 1995)

Nutrient samples were drawn into 45 ml high density polypropylene, narrow mouth, screw-capped centrifuge tubes which were rinsed three times before filling. Standardizations were performed at the beginning and end of each group of analyses (one cast, usually 36 samples) with a set of an intermediate concentration standard prepared for each run from secondary standards. These secondary standards were in turn prepared aboard ship by dilution from dry, pre-weighed primary standards. Sets of 5-6 different concentrations of shipboard standards were analyzed periodically to determine the deviation from linearity as a function of concentration for each nutrient.

Nutrient analyses (phosphate, silicate, nitrate and nitrite) were performed on an ODF-modified 4 channel Technicon AutoAnalyzer II, generally within one hour of the cast. Occasionally some samples were refrigerated at 2 to 6 C for a maximum of 4 hours. The methods used are described by Gordon fIet al.fR [Atla71], [Hage72], [Gord92]. The colorimeter output from each of the four channels were digitized and logged automatically by computer (PC), then split into absorbence peaks. All the runs were manually verified.

Silicate is analyzed using the technique of Armstrong fIet al.fR [Arms67]. Ammonium molybdate is added to a seawater sample to produce silicomolybdic acid which is then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. Tartaric acid is also added to impede PO_4 contamination. The sample is passed through a 15mm flowcell and the absorbence measured at 820nm. ODF's methodology is known to be non-linear at high silicate concentrations (>120 (mM); a correction for this non-linearity is applied in ODF's software.

Modifications of the Armstrong fIet al.fR [Arms67] techniques for nitrate and nitrite analysis are also used. The seawater sample for nitrate analysis is passed through a cadmium column where the nitrate is reduced to nitrite. Sulfanilamide is introduced, reacting with the nitrite, then N-(1-naphthyl) ethylenediamine dihydrochloride which couples to form a red azo dye. The reaction product is then passed through a 15mm flowcell and the absorbence measured at 540nm. The same technique is employed for nitrite analysis, except the cadmium column is not present, and a 50mm flowcell is used.

Phosphate is analyzed using a modification of the Bernhardt and Wilhelms [Bern67] technique. Ammonium molybdate is added to the sample to produce phosphomolybdic acid, then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The reaction product is heated to 55 C to enhance color development, then passed through a 50mm flow cell and the absorbence measured at 820nm.

Nutrients, reported in micromoles per kilogram, were converted from micromoles per liter by dividing by sample density calculated at zero pressure, fIin-situfR salinity, and an assumed laboratory temperature of 25 C.

Na_2SiF_6, the silicate primary standard, is obtained from Fluka Chemical Company and Fischer Scientific and is reported by the suppliers to be >98% pure. Primary standards for nitrate (KNO_3), nitrite ($NaNO_2$), and phosphate (KH_2PO_4) are obtained from Johnson Matthey Chemical Co. and the supplier reports purities of 99.999%, 97%, and 99.999%, respectively.

5679 nutrient analyses were performed. No major problems were encountered with the measurements. The pump tubing was changed three times, and deep seawater was run as a substandard. The temperature stability of the laboratory used for the analyses was fair, at one point late in the cruise failing entirely. Portable fans were then used to restore temperature stability.

B.5.1. Nutrient References

Armstrong, F. A. J., Stearns, C. R., and Strickland, J. D. H., 1967 The measurement of upwelling and subsequent biological processes by means of the Technicon Autoanalyzer and associated equipment. Deep-Sea Research, 14, 381-389.

Atlas, E. L., Hager, S. W., Gordon, L. I., and Park, P. K., 1971. A Practical Manual for Use of the Technicon(rg AutoAnalyzer(rg in Seawater Nutrient Analyses Revised. Oregon State University, Department of Oceanography, 49, Technical Report 215, Reference 71-22.

Bernhardt, H. and Wilhelms, A., 1967. The continuous determination of low level iron, soluble phosphate and total phosphate with the AutoAnalyzer. Technicon Symposia, 385-389.

Brewer, P. G. and Wong, G. T. F., 1974. The determination and distribution of iodate in South Atlantic waters Journal of Marine Research. 1, 25-36.

Gordon, L. I., Jennings, J. C., Jr., Ross, A. A., and Krest, J. M., 1992. A suggested Protocol for Continuous Flow Automated Analysis of Seawater Nutrients in the WOCE Hydrographic Program and the Joint Global Ocean Fluxes Study. OSU College of Oceanography Descr. Chem Oc. Grp. Tech Rpt 92-1

Hager, S. W., Atlas, E. L., Gordon, L. D., Mantyla, A. W., and Park, P. K., 1972. A comparison at sea of manual and autoanalyzer analyses of phosphate, nitrate, and silicate. Limnology and Oceanography, 931-937.

B.6. Preliminary report on lowered and vessel-mounted ADCP measurements

(May 4, 1995)

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Ocean velocity observations were taken on the WHP Indian Ocean Expedition (line I08N) using two acoustic Doppler current profiler (ADCP) systems and accurate navigation data.

The two systems are the hull-mounted ADCP and a lowered ADCP mounted on the rosette with the CTD. The data were taken aboard the R/V KNORR from March 10, 1995 to April 15, 1995 between Colombo, Sri Lanka and Fremantle, Australia. The purpose of the observations was to document the upper ocean horizontal velocity structure along the cruise track, and to measure vertical profiles of the horizontal velocity components at the individual hydrographic stations. The observations provide absolute velocity estimates including the ageostrophic component of the flow.

Figure B.4.1 shows the cruise track and the near surface currents measured by the hull-mounted ADCP for the N/S segment of the cruise. Figures B.4.2 and B.4.3 show the hull-mounted ADCP velocities near the sill at the southern end of the 90E ridge, and the (approximately) E/W section to Fremantle.

B.6.1. Hull-mounted ADCP

The hull-mounted ADCP is part of the ship's equipment aboard the KNORR. The ADCP is a 150 kHz unit manufactured by RD Instruments. The instrument pings about once per second, and for most of the cruise the data were stored as 5-minute averages or ensembles. The user-exit program, ue4, receives and stores the ADCP data along with both the P-code navigation data from the ship's Trimble receiver and the Ashtech gps receiver positions. The P-code data are used as navigation for the ADCP processing. The ship's gyro- compass provides heading information for vector averaging the ADCP data over the ensembles. The user-exit program calculates and stores the heading offset based on the difference between the heading determination from the Ashtech receiver and from the ship gyro. The ADCP transducer is mounted at a depth of about 5 meters below the sea surface.

As setup parameters, we used a blanking interval of 4 meters, a vertical pulse length of 16 meters and a vertical bin size of 8 meters. Data collection during the first 6 days of the cruise used 200s ensembles, and for the remainder of the cruise ensembles were 300s. During testing, 20s ensembles were used.

On the previous leg (I09N) the ADCP signal degraded near the end of the cruise, giving reliable data to only 125m. In order to try to return the signal to a reasonable level prior to the I08N leg, the ADCP was removed from the ship's hull and cleaned on deck and the preamp boards were tested. The ADCP was remounted in the ship's hull in port with the nominal "forward" beam facing nearly due aft (it was previously mounted with the "forward" beam facing 45 degrees starboard of forward). Although the ADCP appeared to be working in port, a bad connection prevented data collection until 3/12 (19:37 Z). After the bad connection was discovered, the cable connecting the RDI acquisition box and the ADCP in the hull was tied in place in an effort to ensure a good connection. Data aquisition proceeded without incident until the end of the cruise, although beam 2 was weaker than 1,3, or 4 for the entire cruise. A significant decrease in signal strength at 13S corresponded to an oxygen and nutrient front and to a simultaneous decrease in return signal from the lowered ADCP.

Final editing and calibration of the ADCP data is not finished. This involves the usual editing of CTD wire interference and the determination of the actual transducer orientation. In addition, the CTD and underway temperature and salinity must be used to correct the speed of sound because the ADCP thermistor was incorrect for much of the cruise. The temperature difference of (ADCP thermistor-CTD) increased approximately linearly from 0 to 8C during the first 28 days, remained at 8C for the next 6 days, and increased again during the last 1.5 days from 8C to 20C. An unusual event in ADCP data acquisition is that during the first week the amplitude of the reference velocity was halved, and then went back to normal. The factor of two is one of two options available in the software, but why the software changed the amplitude has not been determined.

B.6.2. Lowered ADCP

The second ADCP system is the lowered ADCP (LADCP), which was mounted to the rosette system with the CTD. The LADCP yields vertical profiles of horizontal velocity components from near the ocean surface to near the bottom. The first unit used is a broadband, self- contained 150 kHz system manufactured by RD Instruments. We used single ping ensembles. This unit failed after 9 casts, and we switched to the older narrow-band 300KHz system, which averages pings into ensembles prior to data storage. The data from each instrument is transferred to a PC between casts.

With either instrument, vertical shear of horizontal velocity was obtained from each ping (or ensemble). In the BB case, these shear estimates were vertically binned and averaged for each cast. By combining the measured velocity of the ocean with respect to the instrument, the measured vertical shear, and accurate shipboard navigation at the start and end of the station, absolute velocity profiles are obtained (Fisher and Visbeck, 1993). Depth is obtained by integrating the vertical velocity component; a better estimate of the depth coordinate will be available after final processing of the data together with the CTD profile data. The shipboard processing results in vertical profiles of u and v velocity components, from a depth of 60 meters to near the ocean bottom in 20 meter intervals. The zonal velocity in the section which crossed the equator is shown in Figure B.4.4.

CTD casts were made at stations 279-442 on the I08N cruise. Broad Band LADCP casts were made at stations 279-291. Narrow Band LADCP casts were taken at all CTD stations thereafter except 292-293 (NBLADCP installation), 353-354 (erase EPROMs in NBLADCP, replace internal battery pack with DC-DC power converter to allow use of external battery pack), 405-406 (eraseEPROMs), and 421-428 termine a break in cable was caused by shorting the battery across the rosette upon deployment at station 405). Deep BBLADCP casts often have noise problems below 3000 meters or so due to poor instrument range and interference from the return of the previous ping. NBLADCP stations occasionally showed data dropout in the bottom 1000m.

B.6.3. Navigation

The ship used a Trimble P-code receiver for navigation, with data coming in at once per second. We have stored this once per second data for the entire cruise, except for two periods (1/2 day and 2 hours) where 1 minute data were substituted. We also decimated this once per second data by a factor of 10 to 10-second intervals and stored these processed files as daily matlab files of latitude, longitude and time.

The Ashtech receiver uses a four antennae array to measure position and attitude. The heading estimate was used with the gyro to provide a heading correction for the ADCP ensembles. The Ashtech data was stored by the ADCP user-exit program along with the ADCP data.

B.6.4. ADCP References

Fisher, J. and M. Visbeck, 1993; Deep velocity profiling with self-contained ADCPs; J. Atmos. Oceanic Technol., 10, 764-773.

B.7. No preliminary report on chlorofluorocarbon measurements

(April 15, 1995)

B.8. No preliminary report on helium and tritium measurements

(April 15, 1995)

B.9. Preliminary report on bathymetry measurements

(Lynne Talley and Frank Delahoyde, April 15, 1995)

The Knorr's Raytheon Line Scan Recorder was used throughout I08N/I05E both for recording depths and for use with the pinger on the CTD/rosette. Depths were recorded every 5 minutes, entered on the ODF CTD computer, and merged with navigation acquired from the ship's Magnavox MX GPS system via RS-232, logged at one minute intervals. The merged navigation and bathymetry file provides a time series of underway position, course, speed and bathymetry data. These data were used for all station positions, PDR depths, and for bathymetry on vertical sections [Cart80].

The PDR paper rolls and computer records will be taken to Stu Smith at Scripps Institution of Oceanography where the data will be added to the general dataset for the Indian Ocean. The recorded bathymetry differs significantly from that on the Gebco charts at the juncture of Broken Ridge and the Ninetyeast Ridge.

B.9.1. Bathymetry Reference Carter, D. J. T., Wormley, Godalming, Surrey. GU8 5UB. U.K., 1980. Computerised Version of Echo-sounding Correction Tables (Third Edition). Marine Information and Advisory Service, Institute of Oceanographic Sciences.

B.10. Preliminary report on underway IMET measurements

(Michael Thatcher, April 15, 1995)

The following IMET sensors were installed an in use during I08N.

Type	Serial number	Label
Air temperature	119	TMP
Barometric Pressure	118	BPR
Precipitation	113	PRC
Relative Humidity	xx	HRH
Sea Surface Temperature	108	SST
Short Wave Radiation	003	SWR
Wind Speed and Direction	002	WND (3/10 - 3/31)
Wind Speed and Direction	107	WND (3/31 - 4/15)

Data:

The data were logged to ASCII text files, one containing ship navigational information, and the other containing meteorological information. David Newton (SIO) has complete copies of this data which he has reformatted into single combined files, by day with an added error code of "-99" for bad or missing data.

Known problems:

Wind sensor - There was a failing board in the wind sensor which was replaced during the port stop prior to sailing (unit 107). Unfortunately the changed board made matters worse and as a result the wind speed would frequently jump to an unreasonably high value, such as 90 meters per second for a period of one minute and data would also occasionally contain "?" characters. The data logger appears to have recorded the "?" characters in the place of wind direction when they appeared. The "?" were verified to be originating in the wind instrument and not in the data logger. As a result of the two failed boards, the spare wind sensor (unit 002) was re-calibrated and put into use.

Unfortunately, though the data were good, they were not always there and the sensor would cease to provide information. This "timing out" grew worse over time and finally after additional trouble-shooting and swapping yet another board between the two sensors, we were able to re-utilize unit 107 with the WNDSPVN board from unit 002 an the new SCR board received from WHOI. Data logging was constant from this point on (3/31/95). None the less about 12% of this data reflects the errors seen in the previous leg and should be discarded. An entirely new and working wind sensor will be installed during the port stop for the next leg.

The gyre and speed log experienced a problem at the beginning of the cruise due to a power switch on a junction box being inadvertently turned off in the main lab (3/15/95). Once the source of the problem was found and corrected, there were no further large gaps in this area of the data logging.

B.11. No preliminary report on underway pCO2, pN2O measurements
(April 15, 1995)

B.12. No preliminary report on carbon dioxide measurements
(April 15, 1995)

Figures